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DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
SCOTT TURNER, DIRECTOR

INFORMATION CIRCULAR

# PYRITES

## GENERAL INFORMATION

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DEPARTMENT OF COMMERCE - BUREAU OF MINES

# PYRITES

By Robert H. Ridgway

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## INTRODUCTION

This circular outlines salient facts regarding the pyrites industry of the United States and the world. It is founded chiefly upon published information available in the literature of the subject. The United States Bureau of Mines has in its files additional and more detailed data upon many of the subjects presented very briefly here, and will endeavor to assist the mineral industries and the public by giving further information in response to individual inquiries. The bureau will welcome comments, criticisms, and contribu-

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[1] The Bureau of Mines will welcome reprinting of this paper, providing the following footnote acknowledgment is used "Reprinted from U. S. Bureau of Mines Information Circular 6523."

[2] Mining engineer, common metals division, U. S. Bureau of Mines.

tions of data that may assist in making later editions of this circular of information more accurate, or may aid in developing more fully the files pertaining to pyrites.

## PROPERTIES

The term pyrites is the indefinite general trade name for any of the iron-sulphide minerals containing from 25 per cent to over 50 per cent of sulphur. The minerals composing this group are chiefly pyrite, marcasite, and pyrrhotite. The name pyrite is derived from a Greek word meaning fire and alludes to the brilliant sparks produced when the mineral is struck with iron.

Pyrite ($FeS_2$) is one of two forms of iron disulphide. It crystallizes in the isometric system as cubes, the faces of which are often striated, octahedrons, and pyritohedrons (pentagonal dodecahedrons). The crystals are of common occurrence and are often beautifully and sharply developed. The mineral is opaque with a pale brass-yellow color and a bright metallic luster; its streak is greenish or brownish black. It has no distinct cleavage, is brittle, and breaks with a conchoidal to uneven fracture. Pyrite ranges from 6 to 6.5 in hardness, which is unusually hard for a sulphide; it scratches both glass and steel. The specific gravity varies from 4.95 to 5.10. Pyrite when pure contains 53.4 per cent of sulphur and 46.6 per cent of iron, but often it contains small amounts of arsenic, nickel, cobalt, copper, gold, zinc, tin, etc. It is insoluble in hydrochloric acid but when powdered is completely soluble in nitric acid.

Owing to its yellow color, pyrite has been mistaken frequently for gold and hence has earned the name of "fools gold." It is distinguished from gold by its hardness and brittleness, gold being soft and malleable. It is distinguished from chalcopyrite by being harder and by its pale yellow color.

Marcasite (white iron or cockscomb pyrite) has the same chemical composition as pyrite and is difficult to distinguish from the latter, especially when in massive form. It forms tabular crystals in the orthorhombic system but is seldom found in simple crystals. Owing to its multiple twinning, it usually forms groups with jagged outlines and reentrant angles which have suggested the names "cockscomb pyrites," "spear pyrites," etc. It frequently occurs in radiating fibrous masses. Its color is pale yellow to almost white and deepens on exposure. It has a metallic luster, is opaque, and gives a grayish black streak. Marcasite has the same hardness as pyrite (6 to 6.5), but the specific gravity is slightly less, ranging from 4.85 to 4.90. The cleavage is distinct and parallel to crystal faces. The mineral is brittle and its fracture is uneven. It may be distinguished from pyrite by its color, crystal form, and by the sulphur residue formed when the mineral is dissolved in nitric acid.

Pyrrhotite is a mineral of varying composition. Different formulas ranging from $Fe_5S_6$ to $Fe_{16}S_{17}$ have been given; they all conform to the general formula $Fe_nS_n + 1$, with $Fe_{11}S_{12}$ the usually accepted formula. Pyrrhotite is regarded as a solid solution of sulphur in FeS. Pure $Fe_{11}S_{12}$ would contain 38.4 per cent of sulphur and 61.6 per cent of iron. It often contains cobalt, nickel, or copper, occasionally arsenic, and sometimes silver, gold, platinum, and some of the rarer metals. Pyrrhotite crystallizes in the hexagonal system, usually with tabular and sometimes with pyramidal crystals, but it generally occurs in massive form with granular structure. It has a brownish bronze color and metallic luster but tarnishes easily. It is softer than pyrite or marcasite (hardness 3.5 to 4.5) and is brittle. The fracture is uneven and sometimes exhibits a distinct basal cleavage. The mineral is opaque and shows a black streak. The specific gravity ranges from 4.58 to 4.65. Pyrrhotite is magnetic and is often referred to as magnetic pyrites. It is usually distinguished from other minerals by its color, hardness, and magnetic properties.

## OCCURRENCE

Pyrite is widely distributed both geologically and geographically and occurs in rocks of all kinds and of all ages. It crystallizes within a wide range of temperatures, but the important deposits are mainly products of high or intermediate temperatures. It occurs abundantly in veins, disseminated deposits, and as masses along the contact of basic intrusives and sedimentary rocks. The deposits of economic importance usually occur as lenticular masses of great size. Deposits of pyrite may be of igneous, metamorphic or of sedimentary origin.

Outcrops of pyrite deposits are altered by oxidation and hydration to limonite and other iron oxides, and as pyrite is often associated with other valuable metallic minerals these iron-stained gossans frequently indicate valuable metalliferous deposits at depth.

The most important pyrite deposits occur in the province of Huelva, Spain, and the province of Alemtejo, Portugal. Other important deposits occur in Norway, Japan, Italy, Germany, France, and the United States.

Marcasite is much less abundant than pyrite but may occur with it. It is a relatively unstable mineral found mainly near the surface. It occurs in mineral veins as crystals, as nodules in chalk marl, and in coal and clay. It is also found in the lead-zinc ores of the Mississippi Valley.

Pyrrhotite is a high-temperature mineral and is not known to occur in ores of shallow or intermediate depths. It is found scattered in small quantities through igneous and thermometamorphic rocks and in mineral veins or lodes. Large massive deposits in gneiss and crystalline schists near their contact with granite are known. The sulphur content of pyrrhotite (38-39 per cent) is generally too low to be used as a source of sulphur unless impurities such as copper, nickel, or cobalt are present in sufficient quantities to render the deposit economic. Pyrrhotite ores containing copper are important sources of copper and sulphur in the Ducktown Basin of Tennessee. The pyrrhotite ores of Sudbury district in Ontario are mined chiefly for their copper and nickel content.

Analyses of pyrites from various places in the world are shown in the following table:

Table 1.- Analyses of pyrites from various sources[a]
(Per cent)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S | 49.00 | 45.00 | 44.78 | 48.17 | 42.22 | 32.10 | 34.060 | 49.07 | .50 | 46.50 | 48.5 | 38.72 |
| Fe | 43.55 | 42.50 | 37.49 | 42.32 | 36.30 | 35.94 | 53.150 | 44.28 | - | 44.25 | - | 35.94 |
| Cu | 3.20 | 3.50 | - | .34 | 2.63 | .30 | .866 | 3.25 | .70 | 1.00 | 2.1 | 2.24 |
| Zn | .35 | .25 | 4.23 | - | 2.35 | 4.68 | - | - | - | - | - | 4.50 |
| Insol. | 1.70 | - | 11.08 | 4.00 | - | - | - | - | - | - | - | - |
| CaO | .14 | .10 | .87 | - | 0.52 | 1.00 | - | .93 | - | - | Tr. | b5.90 |
| Mn | - | - | - | - | - | - | - | - | - | - | - | 1.42 |
| MgO | - | - | .20 | - | 0.29 | .59 | - | - | - | - | Tr. | c1.07 |
| Sb | - | - | - | - | - | - | - | - | - | - | - | .08 |
| As | .47 | - | .07 | Tr. | .023 | .04 | - | .38 | - | .06 | .01 | .15 |
| Pb | .93 | .20 | .14 | - | - | .50 | - | - | - | - | - | 2.10 |
| Au, oz. | - | - | - | .03 | - | - | - | Var. | - | - | .01 | .00011 |
| Ag, oz. | - | - | - | .44 | - | - | - | Var. | - | - | .40 | .005 |
| $SiO_2$ | - | - | - | - | 15.00 | 13.42 | 2.99 | 2.59 | 1.00-2.00 | 8.00 | 1.75 | 2.95 |
| $Al_2O_3$ | - | - | - | - | 0.69 | - | - | - | - | - | 1.25 | 1.57 |
| Alkali | - | - | - | - | - | - | - | - | - | - | - | 1.84 |
| Bi | - | - | - | - | - | - | - | - | - | - | - | .12 |

a - Columns headed by figures indicate source of ore, as follows: b - $CaCo_3$. c - $MgCo_3$

1. Rio Tinto, Spain.
2. Sulitelma, Norway.
3. Meggen, Germany.
4. Britannia Mining & Smelting Co., Canada (pyrites concentrates).
5. Lokken mine, Norway.
6. Louisa County, Va.
7. Virginia (pyrrhotite).
8. San Domingo, Portugal.
9. Hornet mine, California.
10. Leona Heights mine, California.
11. Skouriotisso mine, Cyprus.
12. Rammelsberg, Germany.

Table 2.- Estimated reserves of pyrite in Spain in 1926, by mines

| Mines | Reserves (metric tons) | | | | Per cent sulphur |
|---|---|---|---|---|---|
| | Actual | Probable | Possible | Total | |
| Concepcion | 1,400,000 | 1,000,000 | | 2,400,000 | 43 |
| San Platon | 750,000 | 500,000 | 1,000,000 | 2,250,000 | 48 to 50 |
| Esperanza | 799,000 | | | 799,000 | 47 to 48 |
| Cueva de la Mora | 3,047,600 | 722,000 | | 3,769,600 | 44 to 45 |
| Carpio | 335,000 | 300,000 | 2,500,000 | 3,135,000 | 48 to 50 |
| San Telmo | 607,000 | 704,000 | | 1,311,000 | 45 |
| Pena del Hierro | 3,000,000 | 1,000,000 | 2,000,000 | 6,000,000 | |
| Rio Tinto | 151,306,050 | 70,000,000 | | 221,306,050 | |
| La Zarza | 35,000,000 | 12,000,000 | 8,000,000 | 55,000,000 | |
| Perrunal y Lomero-Poyatos | 6,000,000 | 2,000,000 | 4,000,000 | 12,000,000 | 47 to 50 |
| La Joya | 400,000 | 600,000 | | 1,000,000 | 49.5 |
| Castillo de Buitron | 1,150,000 | 2,000,000 | | 3,150,000 | 43 to 49 |
| Santa Rosa | 400,000 | 100,000 | | 500,000 | 40 to 45 |
| Romanera | 200,000 | 800,000 | 1,000,000 | 2,000,000 | |
| California-Concordia (Badajoz) | | 400,000 | 600,000 | 1,000,000 | |
| Sotiel Coronada | 1,080,000 | 580,000 | | 1,660,000 | 30 to 44 |
| La Torera | | 1,500,000 | | 1,500,000 | 43.5 |
| Tharsis | 56,500,000 | 42,500,000 | 33,750,000 | 132,750,000 | |
| La Lapilla | 500,000 | 1,500,000 | 1,500,000 | 3,500,000 | |
| Herrerias | 2,000,000 | 2,000,000 | 3,000,000 | 7,000,000 | 47 to 49 |
| Cabezas del Parto | 1,500,000 | 750,000 | 1,250,000 | 3,500,000 | |
| Fronteriza-Vuelta Folsa | 200,000 | 210,000 | 400,000 | 810,000 | |
| Nuestra Senora de Carmen | 40,000 | 100,000 | 500,000 | 640,000 | |
| Castilla de las Guardas | 3,500,000 | 5,000,000 | 2,000,000 | 10,500,000 | 40 to 42 |
| Sililllos y Cuchichon (Sevilla) | 1,671,633 | | 3,500,000 | 5,171,633 | 42 to 47 |
| Segunda Preciosa (Sevilla) | 200,000 | 650,000 | | 850,000 | 38 |
| Caridad (Sevilla) | 1,144,512 | 645,838 | | 1,790,350 | 43 |
| Total | 272,730,795 | 147,561,838 | 65,000,000 | 485,292,633 | |

## WORLD SOURCES

### Spain

Spain has been the principal source of pyrite for many years, and in 1929 it produced about 50 per cent of the world output. The principal producing district is the Huelva district, which is located in an area about 100 miles long and 12 to 18 miles wide extending approximately east and west across the central part of the province of Huelva into the province of Alemtejo, Portugal. This area lies in the Sierra Morena Mountains and is located about 30 miles north of the port of Huelva, from which a large part of the district's output is exported.

The deposits consist of lenses of massive pyrite which occur in slates and porphyry and along the contacts of slate with porphyry or diabase. The lenses vary in size up to 6,000 feet in length, 800 feet in width and over 1,800 feet in depth. The geologic origin of these deposits has been a subject of great controversy for many years, and several theories of origin have been advanced. At present the hydrothermal replacement theory appears to be the most favored. The large pyrite masses are capped with gossans which usually extend more than 200 feet below the surface. The massive pyrite contains varying amounts of chalcopyrite and chalcocite, and some of the richer lenses have made the Huelva district one of the important copper producing districts of the world. The pyrite also contains small quantities of sphalerite, galena, and arsenopyrite. The average sulphur content of the ore shipped from the Huelva district is about 48 per cent. The average copper content is less than 1 per cent and is gradually decreasing.

The reserves of the Huelva district are sufficient for over 100 years operation at the present rate of production. Table 2 gives the reserves of pyrite in Spain by mines as of 1926:[3]

The principal mines are operated by two English companies, the Rio Tinto Co. (Ltd.) and the Tharsis Sulphur and Copper Co. (Ltd.). The former operates the Rio Tinto mines and the latter the Tharsis and La Zarza mines. These mines produce a large part of the total Spanish output and in 1926 contained 84 per cent of the total estimated pyrite reserves of Spain. Brief descriptions of the operations of the two companies follow.

Rio Tinto Co. (Ltd.) The mines of the Rio Tinto company are located at Rio Tinto, about 40 miles northeast of the port of Huelva. The deposits were worked intermittently for precious metals, lead, and copper from several centuries B. C. until 1873 when they were acquired by the present company; since then operations have been continuous and on a constantly increasing scale.

For many years copper was the principal source of revenue, but in recent years pyrite has become the principal product, notwithstanding increased copper production.

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3 - Rubio, -, and Mendizobal, -, Les Reserves Mondiales en Pyrites: Du XIV Congr s G ologique International Espagne vol. 2, Madrid, 1927, p. 464.

About 2,400,000[4] tons of ore is produced annually from large opencuts and underground stopes. The ore is dropped through chutes to haulage tunnels below the present working levels and is then delivered by trains to the various surface plants. The copper content of the ore varies considerably, but the average is under 2 per cent and is gradually decreasing. The ore is graded according to its copper and sulphur content. Ore containing about 3 per cent copper is sent directly to the smelter for the recovery of the copper. The sulphur content is dissipated into the smelter fume. Ore containing from 0.5 to 2 per cent copper is piled in large heaps on the surrounding hillsides and for several years is subjected to a leaching treatment which removes the copper and other soluble impurities and thus increases the sulphur content of the washed ore. The copper in the leaching solutions is precipitated on iron and recovered as cement copper. Ore with high sulphur content and less than 2 per cent copper is marketed directly either as straight sulphur ore containing about 0.3 per cent copper or as cupriferous pyrite with about 1 per cent copper.

The following table summarizes the operations of the company at Rio Tinto in 1929 according to official Spanish statistics.[5]

Table 3.- Operations of the Rio Tinto Co. in 1929

| | Metric tons | Sulphur content, per cent | Copper content, per cent |
|---|---|---|---|
| Ore produced: | | | |
| Direct smelting ore | 288,205 | 33.44 | 3.11 |
| Leaching ore | 517,757 | 47.46 | 1.17 |
| Do., quartzose | 708,583 | 28.99 | 1.55 |
| Shipping ores | 947,650 | 48.25 | 1.69 |
| Total | 2,462,195 | - | - |
| Leaching operations: | | | |
| Ore in heaps, Dec. 31, 1929 | 21,943,446 | - | - |
| Deposited in heaps during 1929 | 1,270,629 | - | - |
| Iron consumed in 1929 | 25,714 | - | - |
| Washed ore removed | 521,471 | 47.46 | - |
| Cement copper produced for market | 11,413 | - | 92.46 |
| Crude cement copper to smelter | 8,664 | - | 64.86 |
| Smelting operations: | | | |
| Materials charged: | | | |
| Rich mineral (sulphide) | 251,383 | - | 3.46 |
| Siliceous copper ore | 72,759 | - | 2.57 |
| Coarse cement copper | 8,652 | - | 64.86 |
| Fluxes (copper-free) | 76,971 | - | - |
| Coke | 17,070 | - | - |
| Blister copper produced | 14,729 | - | 98.99 |

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[4] - American Metal Market, Estimates Rio Tinto Copper Production at 140,000,000 lbs. a Year: Vol. 38, No. 62, p. 2, April 1, 1931.

[5] - Data taken from Consejo De Mineria. Estadistica Minera de Espana: 1929, p. 344-345.

The pyrite reserves of the mines of Rio Tinto as of 1926 were estimated at 221,000,000 metric tons, 46 per cent of the total Spanish reserve and sufficient for nearly 100 years operation at the present rate of production.

Tharsis Sulphur and Copper Co. (Ltd.).- The Tharsis Sulphur and Copper Co. (Ltd.) has been operating in the Huelva district since 1866. The principal mines are La Zarza (Calanas) and Tharsis, both of which are connected by rail with the port of Huelva. La Zarza lies about 15 miles due west of Rio Tinto, whereas the Tharsis deposit is located about 15 miles southwest of La Zarza and 25 miles north of Huelva. These deposits are similar geologically to those at Rio Tinto, but the copper content is too low to justify leaching. According to official Spanish statistics[6] the company produced 672,000 metric tons of ore in 1928, which averaged about 0.6 per cent copper and 48.5 per cent sulphur. Of this output La Zarza contributed 586,000 tons and Tharsis 86,000 tons.

In 1926, the Tharsis and La Zarza mines were estimated to have reserves of 132,750,000 tons and 55,000,000 tons, respectively.

## Norway

The pyrite and cupreous pyrite ores of Norway are a very important factor in the mining industry of that country. Some of the ores were mined for copper as early as the first half of the seventeenth century, but the first attempt to utilize the sulphur was in 1841 when small quantities were mined for a sulphuric acid factory near Trondhjem.

The principal pyrite deposits are distributed along the mountain chain which forms the backbone of Norway and are concentrated largely in three main districts; the Hardanger-Karmo district, the Trondhjem district, and the Grong district. Other deposits of minor importance occur along the west coast. Norway ranks second to Spain in pyrite reserves in Europe and second to Spain in world production.

The ore which averages about 44 per cent sulphur and 2.5 per cent copper is mined by underground methods. The Orkla-Grubeaktiebolag is the largest producing company, accounting for more than half of the total production. The Orkla is its largest and best-equipped mine.

There is only a small domestic consumption of pyrite in Norway, most of the material being exported, largely to Germany.

## Italy

The mining of pyrites is of great significance to the national economy of Italy as a source not only of sulphur but also of iron. Processes have been developed for the recovery of iron from pyrite cinder to supplement the meagre iron-ore supplies of this nation.

Important deposits occur in the provinces of Grosseto and Torino, and deposits of less importance are situated in Genoa and Vicenza. Nearly all of the Italian production comes from the province of Grosseto in the department of Tuscany. The principal mines of

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6 - Consejo De Mineria Estadistica Minera de Espana: 1928, p. 331.

Grosseto are situated at Gavorrano, Ravi, and Boccheggiano and are controlled largely by the Montecatini Corporation.

The production of pyrites in 1929 amounted to 698,550 metric tons, of which the Montecatini mines produced 534,269 tons. These figures include both iron and copper pyrites, the latter amounting to about 15 per cent of the total output. Italian pyrites are largely used in the manufacture of sulphuric acid, of which about 86 per cent is consumed by the superphosphate industry.

## Japan

The mining of pyrites in Japan has been confined largely to this century, but due to increased demand for sulphuric acid, production has increased rapidly to nearly 600,000 long tons in 1928.

Deposits of pyrite are known on Shikoku Island, Honshu Island, and Kyushu. Pyrite occurs in bedded deposits, massive deposits, and as fissure veins, the bedded deposits being by far the most important. The ore is rarely free from copper and in recent years processes have been developed for extracting the copper by a chloridizing roast and subsequent lixiviation. The sulphur is recovered from the pyrites by ordinary roasting to $SO_2$. Cobalt oxide is recovered from the waste liquor, and the residue is used as a raw material for the iron works.

The Yanahara mine operated by the Fujita Mining Co. is the most important pyrite mine in Japan. It is located in the western part of Honshu Island. The ore from this mine contains about 50 per cent sulphur; this is somewhat higher than the average Japanese ore, which usually contains 40 to 45 per cent.

## Germany

The larger part of the pyrites mined in Germany comes from the deposits at Meggen in Westphalia. The orebody consists of high-grade pyrite associated with barytes and a little galena, zinc blende, and chalcopyrite. The deposit has a thickness of 13 feet and has been followed along the strike for a distance of about 1½ miles. The ore runs about 75 per cent iron pyrite ($FeS_2$) and contains approximately 40 per cent of sulphur. Of minor importance is the Rammelsberg deposit, on the northern slope of the Harz Mountains, near the town of Goslar, which has been a producer of pyrites for many years.

## France

France contains large and commercially important deposits of high-grade pyrites, located in the Departments of Rhone, Saone-et-Loire, and Gard.

In the Department of Rhone beds of pyrite exist on both banks of the Brevenne, a tributary of the Saone, for a width of 4 or 5 miles and are the largest producing deposits in France. The principal mines are the Mines de Sain-Bel which are located about 20 kilometers northwest of Lyon near Arbestle. To the north several kilometers is the old mine of Chessy. The pyrite of Sain-Bel and Chessy contains from 45 to 48 per cent of sulphur. Some of the pyrite contains copper up to 4 or 5 per cent but most of it is noncupreous.

The principal deposits in Saone-et-Loire are near Chalmoux where the Mines de Chizeuil are located. The average tenor of the ore is 42 per cent sulphur, with a minimum of 35 per cent.

## Cyprus

An important deposit of pyrite is located near Skouriotissa in the district of Nicosia. The deposit is about 5 miles inland and is connected to the sea by a railroad. The ore contains about 48 per cent of sulphur and 2.5 per cent of copper. It is clean and uniform and has a low arsenic content (.01 per cent). No metallurgical work is done in Cyprus; the mine product is prepared for shipment in a crushing plant on the shore of Morphou Bay, near Pendayia.

## Portugal

Pyrites is mined in Portugal along the southeastern boundary, on an extension of the Spanish pyrites belt. The largest producing mine (is San Domingos in the district of Beja, province of Alemtejo. The mineral occurs as lenticular masses in a mineralized zone 2,000 feet long and 200 feet thick. The ore is cupriferous and contains over 48 per cent sulphur and is similar to that mined at Rio Tinto. Portuguese pyrites is said to be of excellent grade. Other mines in the same district with ores of the same character are the Mina do Aljustrel and Mina Louzal.

## Canada

Pyrites is available in many parts of Canada, but of late most of the production has been a by-product of copper, lead, and zinc mining, the pyrites being obtained in the process of concentrating the ores of these metals. The largest producer of this class of material is the Britannia Mining & Smelting Co., which produces about 70,000 tons of pyrite a year running about 49 per cent of sulphur. Other operations are being equipped to recover by-product pyrite in Canada. The bulk of the known deposits have been found during this century.

## United States

The iron sulphides are widely distributed in the United States. They occur along the Appalachian Mountain region in lenses associated) with schists; in the Middle West associated with coal and lead and zinc deposits; in the Rocky Mountain States in numerous veins and lenses often mixed with the sulphides of other minerals; and in the coast ranges, usually in lenses more or less intimately connected with igneous rock.

No deposits of commercial importance are known or are likely to be found in Connecticut, Delaware, Florida, Iowa, Kansas, Louisiana, Michigan, Minnesota, Nebraska, North Dakota, Rhode Island, or Texas. All other States could furnish pyrites under suitable market conditions, although in Arkansas, Kentucky, Maine, Maryland, Massachusetts, Mississippi, New Hampshire, New Jersey, Oklahoma, and Vermont the probable reserves are small.

The location of the producing deposits in 1930 are shown in Figure 1.

California.- Production of pyrites in California in 1930 came from two mines: the Hornet mine near Keswick, Shasta County, and the Leona Heights mine near Oakland, Alameda County.

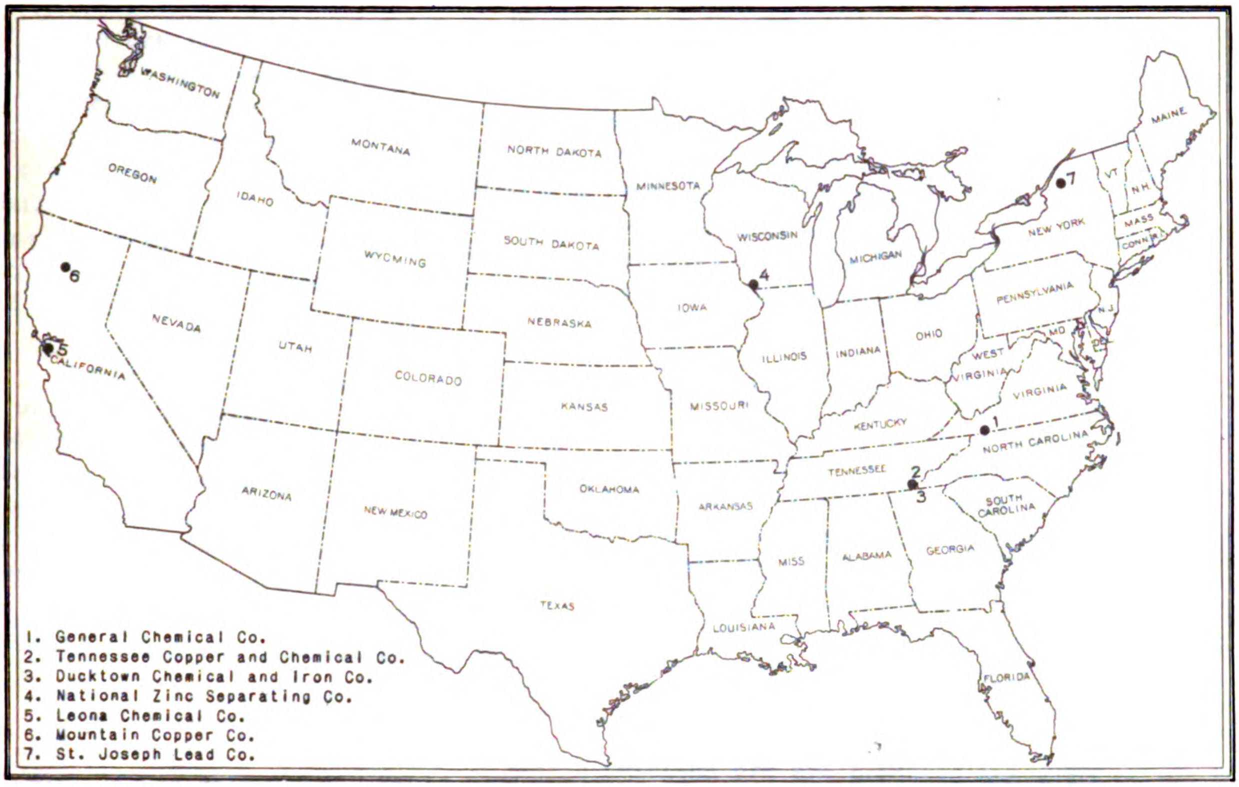

Figure 1.- Map of the United States, showing the location of the companies producing pyrites in 1930

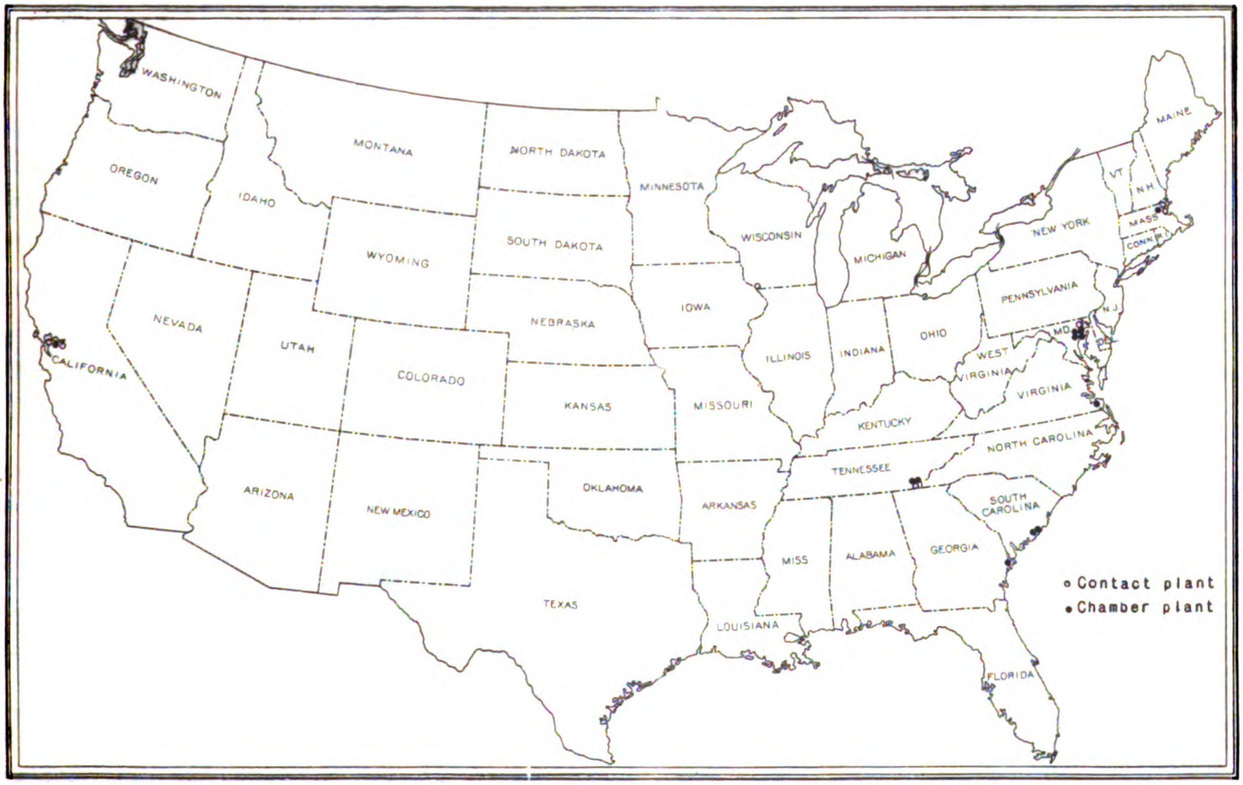

Figure 2.- Map of the United States, showing the location of sulphuric-acid plants operating wholly or partly on pyrites

The ore from the Hornet mine is nearly pure iron pyrite containing 45 to 48 per cent of sulphur, not over 1 to 2 per cent of silica, and an average of 0.7 per cent of copper. The deposit occurs in a large fissure along a shear zone in rhyolite and has been developed for a length of several hundred feet. The pyrite is mined by underground methods and is crushed and screened to various specifications. After having produced some 200 to 300 tons daily for a period of 20 years, operations were suspended at this mine late in 1929 due to competitive pyrite sent into the San Francisco Bay region from the Britannia mine in British Columbia. The company, however, resumed full-scale operations during the third quarter of 1930.

The Leona Heights mine is operated by the Leona Chemical Co. and has a continuous record of production since 1913. The irregular massive deposits occur in a narrow belt of rhyolite that extends more or less continuously along the west front of hills bordering San Francisco Bay from Berkeley nearly to Decoto. The ore consists of pyrite mixed with chalcopyrite and pyrrhotite and a little silica. All of the production is now coming from a section of the deposit which has a thickness of 25 feet and is covered with 60 to 80 feet of overburden. The mine is developed by an adit. The pyrites averages about 47 per cent of sulphur and carries about $1 to $2 per ton in gold and approximately 1 per cent of copper, but the metal values are not recovered. The sulphur content is used by the Stauffer Chemical Co.

Tennessee.- Large quantities of sulphur-bearing ore are produced annually in the Ducktown district in Polk County. The ore from this region is largely pyrrhotite with small amounts of chalcopyrite, and is mined not only for its copper content but also for the sulphur which is used for the manufacture of sulphuric acid. Operations are conducted by the Tennessee Copper Co. and the Ducktown Chemical and Iron Co.

The Tennessee Copper Co. operates the Burra Burra mine and the Eureka mine. The Burra Burra mine is much the larger operation and is the source of the ore smelted and treated in the company's smelter and acid plant at Copperhill, Tenn. The mine operates steadily and furnishes a regular output of about 40,000 tons per month. The Eureka mine is operated irregularly and produces a much smaller tonnage of higher-sulphur ore, the rate of output depending upon the demand for sulphur.

During 1928 about 40 per cent of the combined output of these mines was treated by selective flotation and 60 per cent was smelted directly for copper. The pyrites, which is obtained as flotation concentrates, is separated into both pyrite and pyrrhotite.

The Ducktown Chemical and Iron Co. operates the Mary mine and the Isabella mine, but pyrites is recovered only at the Isabella mill where separate pyrite and pyrrhotite concentrates are made by selective flotation.

None of the pyrites produced in Tennessee enters the market, as both companies use all of their product in the manufacture of sulphuric acid.

Virginia.- Virginia contains a large deposit of pyrrhotite known as the "Great Gossan Lead," which lies in Floyd, Carroll, and Grayson Counties in the southwestern part of the State. The deposit was first mined for copper, and in the early fifties it was actively worked for its rich secondary copper ores. The deposit can be traced by its gossan outcrop for 18 miles and has an average width of about 35 feet. A complete chemical analysis of the pyrrhotite shows that it contains 34.6 per cent of sulphur, 53.15 per cent of iron, 0.866 per cent of copper, and 2.99 per cent of silica. The Gossan mine of the General Chemical Co. at Cliffview, Carroll County, is near the southwest end of the "Great Gossan Lead" and is the only pyrites producer in Virginia at present. The ore is mined by opencut and underground methods and is used for the manufacture of sulphuric acid at Pulaski, Va. Formerly, the roasted material was sintered and used as iron ore in the blast furnace.

Wisconsin.- Pyrites is recovered in Wisconsin from ores produced in the Plattville district which contain principally sphalerite, pyrite, and galena. The ore is mined by underground methods similar to those used in the Southeast Missouri and Joplin districts. The mixed sphalerite-pyrite concentrates from the mills are brought together at the roasting plant of the National Zinc Separating Co. at Cuba City, Wis. A preliminary roast produces an oxide surface on the pyrite particles which makes them magnetic, and after the calcines are cooled, magnetic concentrates are made with a rotating magnetic disk. These magnetic concentrates are then given a further roast to remove more of the sulphur content. The gases from the preliminary and final roasts are used in the manufacture of sulphuric acid. Recently the separation of the pyrite and sphalerite by selective flotation has been attempted.

New York.- There is an occasional production of pyrite from the mines in the Edwards district, St. Lawrence County, N. Y. The most recent production has come from the Balmat mine near the town of Fowler. The production at present is a by-product from the flotation of zinc ores. In previous years the zinc and pyrite were separated by a magnetic process.

## WORLD RESERVES

The world reserves of pyrites are large and widely distributed. Spain, Japan, Norway, Canada, and the Soviet Union are all plenteously supplied with this material. Definite figures concerning the pyrites reserves of the United States are not available, but the total amount that could be utilized is very large. In the Western States there are large reserves of pyrites which contain too little gold and silver to be mined at present, but which could be made available should conditions change. The application of selective flotation to base metal sulphide ores is making available quantities of pyrites which have been lost in the past. Pyrites also has been recovered commercially as coal brasses from the washing and cleaning of coal, and is being recovered from the sands at certain gold mines of the Rand, South Africa.

The world reserves of pyrites were studied by the Fourteenth International Geological Congress at Madrid in 1926, and the following table was compiled from data published by the Congress.[7] At the present rate of consumption the total reserves indicated in the table will supply the world with pyrites for many years. Spain has over 50 per cent of the total estimated supply.

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7 - Du XIV Congres Geologique International Espagne, Les Reserves Mondiales En Pyrites: 2 vols., Madrid, 1927, pp. 1-703.

Table 4.- Estimated World Reserves[1] of Pyrites as of 1926
(Metric tons)

| | Actual reserves | Probable reserves | Possible reserves | Total reserves |
|---|---|---|---|---|
| Europe | 355,782,795 | 234,139,558 | 97,336,000 | 687,258,353 |
| Spain | 272,730,795 | 147,561,838 | 65,000,000 | 485,292,633 |
| Norway | 40,473,000 | 15,715,000 | Very considerable | 56,188,000 |
| Russia | 9,338,500 | 25,077,000 | 1,550,000 | 35,965,500 |
| Portugal | 7,091,000 | - | 15,000,000 | 22,091,000 |
| Italy | 8,904,000 | 10,204,000 | 820,000 | 19,928,000 |
| Germany | 3,192,000 | - | 14,000,000 | 17,192,000 |
| Sweden | 1,581,000 | 14,870,000 | - | 16,451,000 |
| Rumania | 4,253,500 | 6,464,000 | - | 10,717,500 |
| France | 4,519,000 | 2,750,000 | - | 7,269,000 |
| Greece | 2,500,000 | 2,297,720 | 966,000 | 5,763,720 |
| Cyprus | - | 5,000,000 | - | 5,000,000 |
| Austria | 500,000 | 2,200,000 | - | 2,700,000 |
| Finland | - | 2,000,000 | - | 2,000,000 |
| Poland | 700,000 | - | Small | 700,000 |
| Czechoslovakia | Considerable | - | - | - |
| Asia | 101,533,192 | 58,041,135 | 7,500,000 | 167,074,327 |
| Japan | 93,338,192 | 56,651,135 | | 149,989,327 |
| Siberia | 8,195,000 | 1,270,000 | 5,800,000 | 15,265,000 |
| Netherlands East Indies | - | 120,000 | 1,700,000 | 1,820,000 |
| Africa | - | - | 1,700,000 | 1,700,000 |
| Madagascar | - | - | 1,700,000 | 1,700,000 |
| North America | 1,500,000 | 32,000,000 | 10,000,000 | 43,500,000 |
| Canada | 1,500,000 | 32,000,000 | 10,000,000 | 43,500,000 |
| South America | 50,000 | - | - | 50,000 |
| Argentina | 50,000 | - | - | 50,000 |
| Oceania | 6,235,280 | 933,150 | 1,000,000 | 8,168,430 |
| Tasmania | 6,235,280 | 933,150 | - | 7,168,430 |
| Queensland | - | - | 1,000,000 | 1,000,000 |
| Total | 465,101,267 | 325,113,843 | 117,536,000 | 907,751,110 |

1 - Estimated reserves are necessarily understated because of no figures for the United States and other parts of the world. The totals for North America, South America, and Africa are especially incomplete.

## PRODUCTION

Pyrites as mined is never chemically pure but contains admixtures of other base metal sulphides. Consequently, pyrites is produced either as a primary mine product or as a by-product in other mining operations, depending upon the kind and content of the base metal sulphides or other constituents. As a primary mine product, pyrites must necessarily come from deposits capable of yielding a large tonnage of ore which is relatively free from worthless or deleterious materials and which can be cheaply mined and transported to market. Copper, zinc, calcium, magnesium, and sometimes lead are objectionable from the point of view of the acid maker, as they retain sulphur which oxidizes to sulphate and is not available for burning. The lead and zinc otherwise interfere by volatilizing. By-product pyrites is usually in the form of fine concentrates produced by selective flotation of base metal ores, although in the past some use has been made of the pyrite and marcasite removed in the treatment of coal. In Spain where the pyrites is cupriferous, the material is often leached after a period of atmospheric weathering. This method recovers a large percentage of the copper, and the residual ore known as washed pyrites is available for acid making.

The widespread occurrence of pyrite geographically and geologically allows considerable latitude in the production of this commodity. Europe, Asia, Africa, North America, and Australia all have produced significant amounts. Table 5 shows the production of pyrites in the various countries for the decade ending 1929 and for the year 1913.

Spain is by far the largest producer, contributing over 48 per cent of the world's production in 1929. Norway, the second largest producer, (9 per cent of 1929 production) has increased its production over 220 per cent since 1921 and 68 per cent over 1913. The Italian production, which was third in 1929 with a little less than 9 per cent of the total, has shown a strong tendency to increase. Even more pronounced is the trend in Japan, which produced 618,743 tons in 1929, or slightly less than 8 per cent of the total. No other country produced more than 5 per cent, yet this miscellaneous production amounted to over 26 per cent of the total.

Table 6 shows the estimated sulphur content of the world production of pyrite for the decade ending 1929 and for the year 1913. Since 1913 the total sulphur content of the pyrites has increased nearly 16 per cent, but during the four years preceding 1929 the figure was fairly constant.

Table 5.- World production of pyrite for 1913 and for the decade 1920 to 1929

(Metric tons)

| Country | 1913 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Algeria | - | 8,294 | 18,891 | 7,446 | 21,000 | 17,870 | 12,566 | 11,505 | 12,918 | 13,825 | 16,804 |
| Australia | 10,380 | 10,628 | 6,832 | 11,905 | 12,073 | - | - | - | - | - | - |
| Austria | [1]3,586 | 22,764 | 23,142 | 19,400 | 15,136 | 28,046 | 25,072 | 22,293 | 19,328 | 10,000 | - |
| Canada | 143,848 | 158,524 | 30,271 | 16,459 | 25,937 | 21,366 | 14,157 | 16,189 | 46,142 | 62,447 | 70,087 |
| Cyprus [2] | - | 1,422 | 11,737 | 29,667 | 62,509 | 141,050 | 176,036 | 152,776 | 211,462 | 243,913 | 295,772 |
| Czechoslovakia | [3]62,750 | 44,786 | 35,147 | 8,968 | - | 15,935 | 21,594 | 22,512 | 23,300 | 23,626 | 23,005 |
| France | 311,167 | 140,375 | 188,640 | 186,790 | 201,715 | 194,157 | 212,559 | 192,340 | 203,700 | 202,084 | 194,430 |
| Germany | 268,583 | 436,271 | 414,437 | 328,724 | 193,028 | 159,623 | 223,293 | 237,870 | 350,430 | 342,179 | 351,909 |
| Greece | 128,867 | 3,239 | 49,625 | 54,510 | 52,290 | 76,262 | 65,000 | 81,000 | 100,050 | 94,270 | [2]96,911 |
| Hungary | [4] - | - | - | - | - | - | 138 | 176 | 3,666 | 4,222 | 1,023 |
| Italy | 317,334 | 321,589 | 447,899 | 486,000 | 493,271 | 515,781 | 533,737 | 594,479 | 625,338 | 558,390 | 698,550 |
| Japan | 114,576 | 138,409 | 94,987 | 161,503 | 226,067 | 220,456 | 312,627 | 417,513 | 506,089 | 593,972 | 618,743 |
| Norway | 441,291 | 333,011 | 231,123 | 396,411 | 375,161 | 403,411 | 624,375 | 634,836 | 617,044 | 738,535 | 739,597 |
| Poland | - | 264 | 3,966 | 5,518 | 5,708 | 7,843 | 11,217 | 18,850 | 24,596 | 10,668 | 9,410 |
| Portugal | 435,812 | 247,972 | 239,771 | 199,046 | 203,555 | 216,805 | 217,296 | 210,487 | 301,035 | 242,122 | 384,349 |
| Rumania | [5]50,854 | 10,889 | 15,937 | 20,381 | 25,512 | 32,657 | 26,983 | 42,039 | 25,514 | 23,715 | 23,851 |
| Russia | 77,513 | [6]3,748 | [6]11,010 | [6]6,319 | [6]22,167 | [6]27,184 | [6]54,996 | [6]109,394 | [6]225,318 | [6]100,137 | 100,000 |
| Spain | 3,192,465 | 1,355,047 | 2,605,627 | 2,339,589 | 2,652,541 | 2,212,365 | 3,359,240 | 3,654,789 | 3,610,694 | 3,624,819 | 3,867,250 |
| Sweden | 34,319 | 107,326 | 45,772 | 57,321 | 58,297 | 66,353 | 69,873 | 69,759 | 69,239 | 19,996 | 72,055 |
| United Kingdom | 11,610 | 6,766 | 4,006 | 5,760 | 7,019 | 5,658 | 5,373 | 4,307 | 4,968 | 4,440 | 4,441 |
| Union of South Africa | - | 3,217 | 3,955 | 2,848 | 2,966 | 2,349 | 2,512 | 2,448 | 2,254 | 3,754 | 4,116 |
| United States | 346,816 | 315,765 | 159,640 | 175,625 | 193,694 | 170,609 | 196,749 | 226,933 | 307,685 | 317,836 | 338,817 |
| Yugoslavia | [7]7,699 | 3,682 | 27,900 | 11,019 | 25,834 | 26,306 | 38,988 | 53,376 | 57,003 | 64,273 | 61,153 |
| Total | 5,959,470 | 3,673,988 | 4,670,315 | 4,531,209 | 4,875,480 | 4,562,086 | 6,204,381 | 6,775,871 | 7,347,773 | 7,299,223 | 7,972,273 |

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1 - Figures do not include output of provinces subsequently incorporated in Czechoslovakia, Yugoslavia, and Rumania, which is shown under those countries.

2 - Exports.

3 - Includes production from provinces in Austria and Hungary subsequently incorporated in Czechoslovakia, as follows: Bohemia, 1,032 tons; Silesia, 510 tons; Hungary (Iglo), 61,667 tons.

4 - Production in 1913 was from districts subsequently incorporated in Czechoslovakia and Rumania and is shown under those countries.

5 - Production is from districts in Austria and Hungary which subsequent to 1913 were incorporated in Rumania.

6 - Data for year ended September 30.

7 - Output of Bosnia-Herzegovina only.

8 - Serbia only.

Table 6.- Estimated sulphur content of world's pyrite for 1913 and for the decade 1920 to 1929

(Metric tons)

| Country | 1913 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Algeria | - | 3,898 | 8,900 | 3,350 | 9,450 | 8,400 | 5,950 | 5,386 | 6,071 | 6,498 | 7,730 |
| Australia | 4,000 | 4,000 | 2,700 | 4,700 | 4,800 | - | - | - | - | - | - |
| Austria | [1]1,000 | 3,301 | 3,700 | 3,424 | 3,163 | 6,031 | 5,712 | 5,137 | 3,153 | 2,000 | - |
| Canada | 57,000 | 61,333 | 11,079 | 6,260 | 10,045 | 8,838 | 6,883 | 8,142 | 22,887 | 35,007 | 34,000 |
| Cyprus [2] | - | 711 | 5,869 | 14,833 | 31,255 | 70,525 | 88,018 | 76,387 | 105,731 | 121,956 | 147,856 |
| Czechoslovakia | [3]25,000 | 18,000 | 12,000 | 3,600 | - | 6,400 | 8,854 | 9,005 | 9,203 | 9,332 | 9,200 |
| France | 150,000 | 67,000 | 88,213 | 85,963 | 91,250 | 88,432 | 96,587 | 90,748 | 94,380 | 97,000 | 93,000 |
| Germany | 95,391 | 164,749 | 151,202 | 118,053 | 62,767 | 48,144 | 82,041 | 98,939 | 149,531 | 145,866 | 149,963 |
| Greece | 62,000 | 1,571 | 24,068 | 26,437 | 24,277 | 35,401 | 31,525 | 39,577 | 48,884 | 45,360 | [2] 46,500 |
| Hungary | [4] - | - | - | - | - | - | 60 | 70 | 1,500 | 1,700 | 400 |
| Italy | 149,000 | 151,846 | 206,277 | 207,236 | 227,382 | 237,398 | 243,922 | 273,248 | 286,227 | 256,683 | 320,000 |
| Japan | 46,000 | 55,000 | 46,000 | 65,000 | 90,000 | 88,000 | 125,000 | 167,000 | 202,000 | 237,000 | 250,000 |
| Norway | 195,335 | 141,567 | 122,919 | 170,241 | 161,721 | 173,389 | 266,903 | 272,330 | 266,855 | 321,630 | 323,844 |
| Poland | - | 100 | 1,600 | 2,600 | 2,800 | 3,100 | 4,500 | 7,500 | 9,800 | 4,300 | 3,835 |
| Portugal | 210,000 | 119,000 | 115,000 | 96,000 | 98,000 | 104,000 | 104,000 | 101,000 | 145,000 | 116,000 | 84,000 |
| Rumania | [5]23,000 | 4,600 | 6,700 | 8,600 | 10,700 | 13,700 | 11,300 | 17,600 | 11,000 | 10,000 | 10,000 |
| Russia | 31,000 | [6]1,500 | [6]4,400 | [6]2,500 | [6]9,000 | [6]11,000 | [6]16,800 | [6]44,000 | [6]90,000 | [6]41,000 | 40,000 |
| Spain [9] | 1,496,000 | 630,665 | 1,190,784 | 1,072,017 | 1,216,052 | 1,027,600 | 1,539,846 | 1,658,391 | 1,609,776 | 1,439,747 | 1,425,000 |
| Sweden | 12,698 | 39,603 | 17,867 | 22,105 | 22,479 | 25,616 | 26,695 | 27,073 | 32,126 | 12,394 | 32,092 |
| United Kingdom | 4,600 | 2,700 | 1,600 | 2,300 | 2,800 | 2,300 | 2,100 | 1,700 | 2,000 | 1,800 | 1,800 |
| Union of South Africa | - | 1,400 | 1,800 | 1,200 | 1,300 | 1,100 | 1,100 | 1,100 | 1,000 | 1,700 | 1,900 |
| United States | 139,000 | 125,958 | 68,201 | 73,736 | 77,465 | 68,490 | 76,998 | 87,042 | 115,226 | 115,124 | 122,303 |
| Yugoslavia | [7]3,500 | 1,700 | 13,000 | 5,000 | 12,000 | [8]12,000 | 18,000 | 24,000 | 26,000 | 29,000 | 27,000 |
| Total | 2,704,524 | 1,600,202 | 2,103,879 | 1,995,155 | 2,168,706 | 2,039,864 | 2,762,794 | 3,015,375 | 3,238,350 | 3,051,097 | 3,130,423 |

1 - Figures do not include output of provinces subsequently incorporated in Czechoslovakia, Yugoslavia, and Rumania, which is shown under those countries.

2 - Exports.

3 - Includes production from provinces in Austria and Hungary subsequently incorporated in Czechoslovakia.

4 - Production in 1913 was from districts subsequently incorporated in Czechoslovakia and Rumania and is shown under those countries.

5 - Production is from districts in Austria and Hungary which subsequent to 1913 were incorporated in Rumania.

6 - Data for year ended September 30.

7 - Output of Bosnia-Herzegovina only.

8 - Serbia only.

9 - Includes cupriferous pyrite, some of which has relatively low sulphur content which is not recovered.

## USES AND SUBSTITUTES

The principal uses for pyrites are in the manufacture of sulphuric acid and sulphite wood pulp, for which purposes it is burned or roasted to furnish sulphur dioxide, an essential raw material in these industries. This operation generally takes place in kilns and furnaces of various types usually classed as lump burners and fines burners. In the mining and crushing of pyrites a considerable quantity of "fines" or "smalls" is made which formerly were unmarketable owing to the difficulty with which they were roasted. However, the introduction of efficient mechanical burners for roasting this fine material made available large quantities of ore which otherwise would have been of no economic value, such as pyrites ore, which has a tendency to break fine, and the pyrites concentrates recovered by selective flotation from plants treating base metal sulphide ores.

The lump burners or kilns are similar to simple deep bed coal fireplaces. They are rectangular in horizontal section, the grate area being about 5 feet wide and 4 to 6 feet long. The kilns are usually erected in batteries of 16 to 32 furnaces, the units being arranged in two rows, back to back, with a common central wall.

The fines burners are usually cylindrical multiple-hearth furnaces of the McDougal type with various modifications such as the water-cooled Wedge furnace and the Herreshoff furnace.

Recently there has been developed in Canada a new process for roasting fine pyrites in which dry air-floated material is kept in suspension in a vertical combustion chamber until the iron and sulphur have been oxidized. The resulting iron oxide settles to the bottom of the chamber and the gaseous sulphur products rise to the top where they are withdrawn for further treatment. The process is fully described by Freeman.[8] Similar operations are being conducted experimentally at several plants in the United States.

The iron-oxide residue from pyrites burners can be converted into a suitable raw material for the iron blast furnace by sintering. The sulphur-dioxide gas is usually treated for the removal of suspended dust particles before it is used in the manufacture of sulphuric acid or sulphite wood pulp.

Pyrite has long been a competitor of native sulphur in the manufacture of acid and sulphite wood pulp. At present there is a distinct preference for native sulphur because of the ease of obtaining a constant flow of clean sulphur-dioxide gas, and, where necessary, of obtaining higher concentrations of the gas. It is necessary to handle and transport more than 2 tons of pyrite in order to obtain the equivalent sulphur content of 1 ton of native sulphur. The technical improvements made in burners of fine pyrites has helped the position of pyrites some, but where fines burners are employed, a dust chamber to arrest the dust carried forward from the furnaces is necessary. With large reserves of native sulphur available in the United States coupled with the simplicity of burning native sulphur it is not surprising that pyrites is receiving a diminishing percentage of the sulphur market. The use of pyrites now depends entirely on a very favorable price differential per unit of sulphur.

At present only about 20 per cent of the sulphuric acid produced in the United States is derived from pyrites, whereas in Europe sulphuric acid is largely made from pyrites

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8 - Freeman, Horace, The Utilization of Pyrites in Pulp in Acid Manufacture: Canadian Min. and Met. Soc., Bull. 216, Apr., 1930, pp. 471-476.

in Great Britain and Germany appreciable quantities are made from sulphur. European producers of pyrites are developing processes for the production of elemental sulphur from pyrites.

Pyrite is also used in smelters as a fluxing agent to furnish iron for the slag. In pyritic and semipyritic smelting, the oxidation of pyrite provides some heat for the smelting operation, and the resultant sulphur-dioxide gas is sometimes used in the manufacture of sulphuric acid. Pyrite containing gold and silver is frequently treated in copper and lead smelters, where its precious metal content is recovered in the metal bullion. The pyrites used in smelting operations seldom is obtained in the open market.

Minor uses of pyrites are in radios, jewelry, vermillion paints or for the manufacture of copperas, which is used in dyes, writing ink, wood preservatives, disinfectant, and certain kinds of fertilizers. In late historic times it was used in some of the old wheellock guns.

Figure 2 shows the location of sulphuric-acid plants in the United States which use pyrite as a raw material.

## CONSUMPTION

The first application of pyrites in the making of sulphuric acid was described in an English patent in 1818, but there was not much development along this line until 1838, when the Sicilian Government granted a monopoly for the exportation of Sicilian sulphur to the Marseilles firm of Taix & Cie, which immediately tripled the price of sulphur. Search for substitutes for sulphur in the manufacture of sulphuric acid was instituted, and in 1839 pyrites was first used on a large scale in England for this purpose. In the succeeding years pyrites gradually but steadily replaced sulphur for the production of sulphuric acid, notwithstanding the fact that the Sicilian monoply of sulphur did not endure and the price was returned to normal.

In 1891 the sulphur content of the pyrite consumed in the United States was 93,233 long tons, which was obtained from domestic ores and foreign ores in about equal amounts. At the beginning of the century (1900) this had increased to 237,195 tons, with 39 per cent being furnished by domestic ores. The amount of pyrites consumed in the United States continued to increase until in 1916 when the consumption of pyrites - that is, domestic production plus imports - amounted to about 740,000 tons, with over 75 per cent of the ore coming from abroad. Meanwhile extensive reserves of cheaply mined sulphur had been developed in the United States.

The advent of the World War had a tremendous effect on the consumption of pyrite in the United States. The need of transportation facilities for essential traffic between the United States and Europe resulted in the drastic curtailment of bottoms engaged in other traffic, and imports of pyrites from Spain and Portugal fell off materially. American manufacturers of sulphuric acid then turned to brimstone as a source of sulphur. At the close of the war many industries, because of an assured domestic supply, continued to use brimstone rather than change their plants to handle pyrites. Thus the consumption of pyrites in the United States has been impeded by an increasing application of sulphur in the manufacture of acid.

Pyrites is the principal source of sulphur for the manufacture of sulphuric acid in Europe, where approximately 50 per cent of the world's output of the acid is made. Considerable acid in Europe is made from zinc blende and smaller amounts from spent oxide and native sulphur. Recently gypsum has been used as a raw material in acid manufacture but as yet is of minor importance.

In 1900, the world's consumption of sulphur amounted to 2,500,000 metric tons, with about 80 per cent coming from pyrites. In 1929 the world's consumption had risen to approximately 6,000,000 tons, derived almost equally between pyrite and sulphur. The pyrites producers have been forced to a lower unit price of sulphur than the unit price of sulphur in native sulphur in an endeavor to retain their share of the markets. Another important competing factor is the very large quantity of sulphuric acid now manufactured at zinc smelters and to a lesser extent at copper smelters. With the present tendency away from pyrites to sulphur, methods are being perfected for the production of sulphur from pyrites. Plants are now being constructed in Norway and Spain for this purpose.

## MARKET AND PRICE

The principal market for pyrites in the United States is located along the Atlantic seaboard where Spanish pyrites, mined cheaply and favored by cheap ocean transportation, can compete with native sulphur in the fertilizer industry. The chief marketing point is New York, but there are subagents at various points along the Atlantic seaboard. As it is necessary to handle over 2 tons of pyrite to obtain a sulphur content equal to 1 ton of native sulphur, the cost of transportation is a controlling factor in the marketing of pyrites. Consequently, only pyrites produced in close proximity to markets for sulphuric acid can be marketed profitably. Most of the domestic pyrites is produced by consuming companies, so that only a small part enters the open market. Pyrites produced in California is marketed in the San Francisco Bay region. Some Canadian pyrites is marketed in the Eastern States.

Pyrites is usually sold at a price per unit of sulphur, and a specified sulphur content is usually guaranteed. The unit is 1 per cent per ton of 2,240 pounds or 22.4 pounds of sulphur. Two grades are recognized, lump and fines. Lump ore ranges in size from 2 to 10 inches, and the proportion of fines must not exceed 10 per cent past a 1/2 or 3/8 inch screen All material past 1/2 or 3/8 inch screen is sold as fines, which usually sell for 2 cents less per unit of sulphur than lump ore. Sometimes run-of-mine ore is sold, but this is objectionable, as it usually carries a large proportion of fines.

No well-defined premiums or penalties are recognized by the trade, but where transactions involve uncertainty, special clauses are inserted in the sales contract. A premium is usually allowed where the sulphur content exceeds the guarantee basis and a penalty where it is less. No allowance is made for moisture except where it is in excess of 1 per cent. Impurities are present, usually in small amounts; zinc and lead where percentages approximate 3 per cent or more are objectionable; arsenic in excess of 1 per cent is considered objectionable in acid manufacture, as it renders the acid unfit for certain uses and has a deleterious effect on some catalysts used in the contact process. Pyrites containing recoverable amounts of copper may be sold outright to the buyer who sells the residual iron oxide after the copper has been removed by leaching, or it may be leased to a buyer who pays only a specified price for the sulphur content, the seller retaining ownership of the sinter.

The following table shows a typical analysis of imported Spanish pyrites which is marketed on our eastern seaboard:

Table 7.- Typical analyses of Spanish pyrites imported into the United States[1]

| | Pyrites lumps, per cent | Pyrites fines, per cent | Washed pyrites, per cent |
|---|---|---|---|
| Copper | 1.75- 2.00 | 1.75- 2.00 | 0.30 - 0.45 |
| Lead | .94 | 1.10 | .50 - .80 |
| Bismuth | 0.14 | .017 | .005 - .01 |
| Arsenic | .45 | .47 | .25 - .35 |
| Antimony | .055 | .062 | .010 - .020 |
| Sulphur | 47.47 | 46.43 | 48.50 - 50.00 |
| Phosphorus | .007 | .008 | .007 - .010 |
| Iron | 40.41 | 39.27 | 42.0 - 43.50 |
| Alumina | 1.69 | 1.25 | .10 - .20 |
| Zinc | 1.31 | 1.37 | .35 - .55 |
| Manganese | .041 | 0.60 | .01 - .02 |
| Nickel and cobalt | .122 | .134 | .13 - .132 |
| Lime | .324 | .370 | .20 - .30 |
| Magnesia | .115 | .130 | .10 - .15 |
| Siliceous residue | 3.59 | 4.90 | 2.50 - 4.00 |
| Silver | .0047 | .0050 | .004 - .005 |
| Gold | .0007 | .00007 | .0007 - .00007 |

1 - Hearings before a subcommittee of the Committee on Finance, United States Senate, Seventy-first Congress, 1929, p. 663.

The price of Spanish pyrites per long-ton unit, c.i.f. Atlantic ports from 1926 to 1930, inclusive, is shown in the following table:

Table 8.- Prices of Spanish pyrites per long-ton unit, c.i.f. Atlantic ports, from 1926 to 1930, inclusive[1]

| Year | January 1 | April 1 | July 1 | October 1 |
|---|---|---|---|---|
| 1926 | $0.11½-.12 | $0.12-.13 | $0.12-.13 | $0.12-13 |
| 1927 | .12 -.13 | .13-.13¼ | .13-.13¼ | .13-13¼ |
| 1928 | .13 -.13¼ | .13-.13¼ | .13-.13¼ | .13-13¼ |
| 1929 | .13 -.13¼ | .13-.13¼ | .13-.13¼ | .13-13¼ |
| 1930 | .13 -.13¼ | .13-.13¼ | .13-.13¼ | .13-13¼ |

1 - Data taken from Oil, Paint and Drug Reporter.

## IMPORTS AND EXPORTS

The United States imports large quantities of pyrites. Over half of the domestic consumption is met by foreign material. Table 9 shows the imports of pyrite by countries of origin during the last decade as compared with those of 1913. While there was a noticeable drop in the imports of pyrites immediately following the war, there has been a large increase since 1924, but at present imports of pyrites are only 50 per cent of the pre-war figure. Table 10 shows the distribution of imports by customs districts for the decade ending 1929 and for 1913.

Table 9.- Imports of pyrites into the United States by countries of origin, 1913 and 1921 to 1930

(Long tons)

| Country | 1913 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Canada | 31,293 | 7,000 | 66 | 10,443 | 3,935 | 1,211 | 1,046 | 9,203 | 56,956 | 68,243 | 42,117 |
| Cuba | - | 16,250 | 1,000 | - | - | - | - | - | - | - | - |
| Portugal | 118,732 | - | - | - | - | - | - | - | - | - | - |
| Spain | 814,534 | 191,515 | 266,872 | 252,862 | 242,786 | 275,174 | 365,105 | 241,591 | 393,840 | 446,093 | 325,992 |
| Other countries | - | 1,464 | 7,516 | 390 | 16 | - | - | - | 7,468 | - | |
| Total | 964,559 | 216,229 | 275,454 | 263,695 | 246,737 | 276,385 | 366,151 | 250,794 | 458,264 | 514,336 | 368,114 |

Table 10.- Imports of pyrites into the United States by customs districts, 1913 and 1921 to 1930

(Long tons)

| Customs districts | 1913 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Buffalo | - | - | 40 | 10,401 | 233 | 995 | 79 | 174 | 120 | 413 | 90 |
| Chicago | - | 7,000 | - | - | - | - | - | - | 28 | - | - |
| Georgia | 114,854 | 3,566 | - | 11,125 | 9,451 | 7,713 | 7,179 | 3,650 | 5,915 | - | 5,554 |
| Jacksonville | 20,093 | - | - | - | - | - | - | - | - | - | - |
| Maine and New Hampshire | - | - | - | - | - | - | - | - | - | 25,751 | - |
| Maryland | 185,546 | 67,539 | 93,572 | 81,094 | 89,741 | 94,331 | 128,128 | 74,827 | 140,090 | 182,249 | 175,611 |
| Massachusetts | 30,463 | - | - | - | - | - | - | - | 14,907 | - | - |
| Mobile | 42,795 | - | - | - | - | - | - | - | - | - | - |
| New Orleans | 26,894 | - | - | - | - | - | - | - | - | - | - |
| New York | 128,823 | 26,680 | 29,572 | 46,078 | 38,411 | 24,016 | 29,693 | 25,895 | 70,231 | 54,331 | 42,145 |
| North Carolina | 37,311 | - | 1,000 | - | - | - | - | - | - | - | - |
| Ohio | - | - | 1 | - | 3,500 | 36 | - | - | - | - | - |
| Pensacola | 19,902 | - | - | - | - | - | - | - | - | - | - |
| Perth Amboy | 69,434 | - | - | - | - | - | - | - | - | - | - |
| Philadelphia | 147,258 | 104,330 | 143,165 | 94,549 | 87,122 | 128,568 | 174,476 | 120,309 | 153,644 | 166,056 | 87,178 |
| San Francisco | - | - | - | 390 | - | - | 200 | 7,488 | 50,147 | 52,514 | 7,990 |
| South Carolina | 85,213 | - | 2,000 | 10,801 | 10,745 | 13,546 | 14,272 | 8,980 | 11,792 | 5,696 | 7,322 |
| St. Lawrence | - | - | 25 | - | - | - | - | - | - | - | - |
| Vermont | 27,244 | - | - | - | 2 | 23 | - | 1,280 | 6,554 | 17,326 | - |
| Virginia | 10,632 | 7,114 | 6,079 | 9,215 | 7,352 | 7,000 | 11,357 | 7,930 | 4,729 | 10,000 | 27,778 |
| Washington | - | - | - | 42 | 200 | 157 | 767 | 261 | 107 | - | 14,446 |
| Undistributed | 18,097 | - | - | - | - | - | - | - | - | - | - |
| Total | 964,559 | 216,229 | 275,454 | 263,695 | 246,757 | 276,385 | 366,151 | 250,794 | 458,264 | 514,336 | 368,114 |

Spain and Norway have the largest export trade in pyrites. Other countries notably Italy, France, and Germany have some export trade but also have a large import trade especially France and Germany. The production from Cyprus and Portugal is exported entirely to foreign markets. Tables 11 and 12 show exports of pyrite from Spain and Norway during the period 1925 to 1929.

Table 11.- Exports of pyrites from Spain by countries, 1925 to 1929

(Metric tons)

| Country | 1925 |  | 1926 |  | 1927 |  | 1928 |  | 1929 |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | Non-cupreous | cupreous | Non-cupreous | cupreous | Non-cupreous | cupreous | Non-cupreous | cupreous | Non-cupreous | cupreous |
| Algeria | 8,902 | - | 20,994 | - | 31,187 | 5,081 | 22,394 | - | 29,499 | 7,821 |
| Argentina | - | - | - | - | - | 10,705 | 12 | - | - | - |
| Austria | - | 11,242 | - | 2,843 | - | - | - | - | - | - |
| Belgium | 155,208 | 32,242 | 110,257 | 40,328 | 146,538 | 23,481 | 192,918 | 13,537 | 260,268 | 16 |
| Denmarck | 11,020 | 55,545 | 21,681 | 38,649 | 17,337 | 47,350 | 22,541 | 64,636 | 16,286 | 68,423 |
| Finland | - | - | - | - | 3,007 | - | - | - | - | - |
| France | 581,563 | 435 | 628,308 | - | 537,723 | - | 505,191 | - | 556,018 | 14 |
| Germany | 111,349 | 90,637 | 89,189 | 78,248 | 146,591 | 153,442 | 82,941 | 150,453 | 89,262 | 168,850 |
| Great Britain | 157,985 | 83,919 | 157,926 | 70,761 | 179,231 | 71,571 | 163,411 | 79,192 | 182,181 | 121,652 |
| India | - | - | - | - | - | 6,097 | - | - | - | - |
| Italy | 93,323 | 10,951 | 54,085 | 24,500 | 48,906 | 22,687 | 25,861 | 16,596 | 64,411 | 12,191 |
| Morocco | 5,614 | - | 4,655 | - | 6,446 | - | 7,491 | - | 7,397 | 201,033 |
| Netherlands | 245,108 | 227,117 | 245,309 | 184,675 | 418,881 | 267,072 | 508,842 | 228,931 | 459,649 | - |
| Norway | 7,641 | - | - | - | - | - | - | - | - | 1,581 |
| Portugal | - | - | - | - | - | - | 4,887 | - | - | - |
| Sweden | - | 4,136 | - | 2,432 | - | 14,257 | - | 8,972 | 18,636 | 13,189 |
| U. S. A. | 21,401 | 320,904 | 13,699 | 333,742 | 17,435 | 269,479 | 135,661 | 296,810 | 126,258 | 317,126 |
| U. S. S. R. | - | - | 4,516 | - | - | - | - | - | - | - |
| Total | 1,399,114 | 837,128 | 1,350,619 | 776,178 | 1,553,282 | 891,222 | 1,672,150 | 859,117 | 1,809,865 | 911,896 |

Table 12.- Exports of pyrites from Norway by countries, 1925 to 1929

(Metric tons)

| Country | 1925 |  | 1926 |  | 1927 |  | 1928 |  | 1929 |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  | Non-cupreous | Cupreous | Non-cupreous | Cupreous | Non-cupreous | Cupreous | Non-cupreous | Cupreous | Non-cupreous | Cupreous |
| Belgium | - | 28,550 | 1,680 | 26,975 | 1,715 | 19,525 | 3,750 | 20,080 | 6,084 | 14,506 |
| Denmark | 1,986 | 25,699 | 3,090 | 36,324 | 1,505 | 6,461 | - | 4,028 | - | 3,772 |
| Danzig | - | - | - | - | - | - | 2,300 | - | 20,105 | - |
| Finland | - | - | 3,800 | - | 5,580 | - | - | - | - | - |
| France | 4,315 | 23,679 | 1,880 | 64,145 | 18,445 | 51,262 | 1,990 | 70,188 | - | 55,038 |
| Germany | 62,657 | 207,501 | 88,124 | 193,985 | 108,084 | 213,916 | 147,167 | 216,823 | 118,750 | 267,160 |
| Great Britain | 20,183 | 6,805 | 12,407 | 3,300 | 18,249 | 11,382 | 17,569 | 8,427 | 16,435 | 21,175 |
| Lithuania | - | - | - | 2,100 | - | 8,095 | - | 8,825 | 5,834 | 2,376 |
| Netherlands | - | 18,570 | 1,056 | 11,550 | 1,800 | - | 2,810 | 550 | 12,874 | - |
| Poland | - | - | - | - | - | - | - | - | - | - |
| Russia | - | - | - | - | - | - | - | - | - | - |
| Sweden | 1,912 | 136,814 | 17,694 | 114,662 | 23,524 | 113,594 | 32,806 | 108,904 | 24,164 | 88,259 |
| Total | 91,053 | 447,618 | 129,731 | 453,041 | 178,902 | 424,255 | 208,392 | 437,825 | 204,246 | 452,286 |

Table 13.- Exports of pyrites from Cyprus by countries of destination, 1924 to 1928
(Long tons)

| Country | 1924 | 1925 | 1926 | 1927 | 1928 |
|---|---|---|---|---|---|
| Belgium | 1,328 | - | - | - | - |
| Egypt | - | - | 3,500 | - | - |
| France | - | 3,101 | 3,200 | 6,800 | 2,400 |
| Germany | 49,041 | 67,880 | 59,872 | 52,250 | 42,635 |
| Holland | 7,500 | 30,123 | 17,454 | 34,110 | 57,099 |
| Italy | 56,396 | 62,955 | 56,337 | 101,604 | 100,826 |
| Poland | - | - | - | - | 18,300 |
| United Kingdom | 13,923 | 9,196 | 10,000 | 13,358 | 18,800 |
| Total | 128,188 | 173,255 | 150,363 | 208,122 | 240,060 |

Table 14.- Exports of pyrites from Portugal by countries of destination, 1923 to 1927
(Metric tons)

| Country | 1923 | 1924 | 1925 | 1926 | 1927 |
|---|---|---|---|---|---|
| Belgium | 33,328 | 37,627 | 17,274 | 21,796 | 40,426 |
| England | 36,991 | 23,519 | 18,189 | 13,139 | 16,447 |
| France | 73,943 | 100,968 | 108,097 | 88,544 | 84,904 |
| Germany | 21,680 | 3,364 | 113 | - | 4 |
| Holland | 13,085 | 16,500 | 2,921 | - | 2,596 |
| Italy | - | - | 2,429 | 11,161 | 15,499 |
| Spain | 1 | - | - | - | - |
| Sweden | 3,580 | - | - | - | - |
| United States | - | - | - | 1,747 | 674 |
| Total | 182,608 | 181,978 | 149,023 | 136,387 | 160,548 |

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